DSN/Flight Project
Interface Design

RSS-10
DSN Open-Loop
Radio Science System

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Notice

Change 1 reformatted the module to provide a better online presentation. There was no change in content.

Contents

Illustrations

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1. Introduction

1.1 Purpose

This module describes the capabilities of the Open-Loop Radio Science System (RSS) for supporting various radio science experiments.

1.2 Scope

This module outlines the Open-Loop Radio Science System functions, architecture, and data interfaces. System performance characteristics and operational configurations are also covered. Although radio science experiments can include uplink support and closed-loop receiver tracking, this module emphasizes a description of the open-loop recording capability, which is used solely for radio science support. Details of closed-loop Doppler tracking can be found in TRK-20. Details of the uplink functions can be found in the TCI modules and in CMD-10.

2. General Information

The Radio Science System supports radio-science experiments, which use spacecraft radio-frequency signals to remotely probe features of the solar system. By measuring perturbations of the radio-frequency wave as it travels between the spacecraft and the ground stations, characteristics of obstacles or media in the path may be studied. Targets for radio-science experiments include planets and planetary atmospheres and rings. Non planetary subjects include gravitational radiation and solar plasma. Details of Radio Science System applications may be found in JPL Publication 80-93, *The Deep Space Network as an Instrument for Radio Science Research*.

Observables for radio-science experiments are the frequency, phase, and amplitude of the communication signal's carrier. The DSN RSS has been designed to enable accurate measurement of these observables.

2.1 Functions

The functions of the Radio Science System can be summarized as follows:

- Generation and transmission of an uplink carrier signal to the spacecraft with a pure spectrum, including low phase noise and stable frequency.

- Acquisition, downconversion, digitization, and recording of the downlink carrier with minimal distortion to its frequency, phase, and amplitude characteristics.

2.2 Architecture

The radio-science (RS) capability of the DSN encompasses several subsystems. Support for all experiments includes the Antenna, Microwave, and Receiver Subsystems (including the open-loop and closed-loop receivers). The Ground Communications Facility (GCF) transmits data from a tracking station - at one of the three Deep Space Communication Complexes (DSCC) - to the Network Operations Control Center (NOCC) at JPL, where experiments are monitored. Some experiments require two-way tracking, so the Exciter and Transmitter Subsystems are used. In addition, the Frequency and Timing and Monitor and Control Subsystems provide support. These subsystems may all be used in conjunction with the radio-science open-loop receivers; experiments may also use closed-loop Doppler and ranging. The Radio Science System is diagrammed in Figure 1.

The Open-Loop Receiver Subsystem is diagrammed in Figure 2. There are two kinds of open-loop receivers: the Radio Science IF-VF Downconverter (RIV) used by the 70 m and 34 m high-efficiency (HEF) subnet and the Multimission Receiver (MMR) used by the 34 m Standard (STD) subnet. The 34 m beam waveguide (BWG) antennas, as they are built, may also be used to support experiments, though they have not been specifically designed for RS performance. The 34 m BWG RS architecture follows that of the 34 m HEF and 70 m antennas.

Antennas supported by the RIV use a fixed-frequency downconverter to perform the RF-IF downconversion; those supported by the MMR use the MMR Downconverter, which is programmable. As shown in the diagram, each station is supported by one open-loop receiving string which consists of an RIV or MMR receiver and a DSCC Spectrum Processor (DSP) data handler. One variation on this architecture is the inclusion of a second RIV/DSP string at DSCC-40. The RSS has limited receive frequency ranges for S-

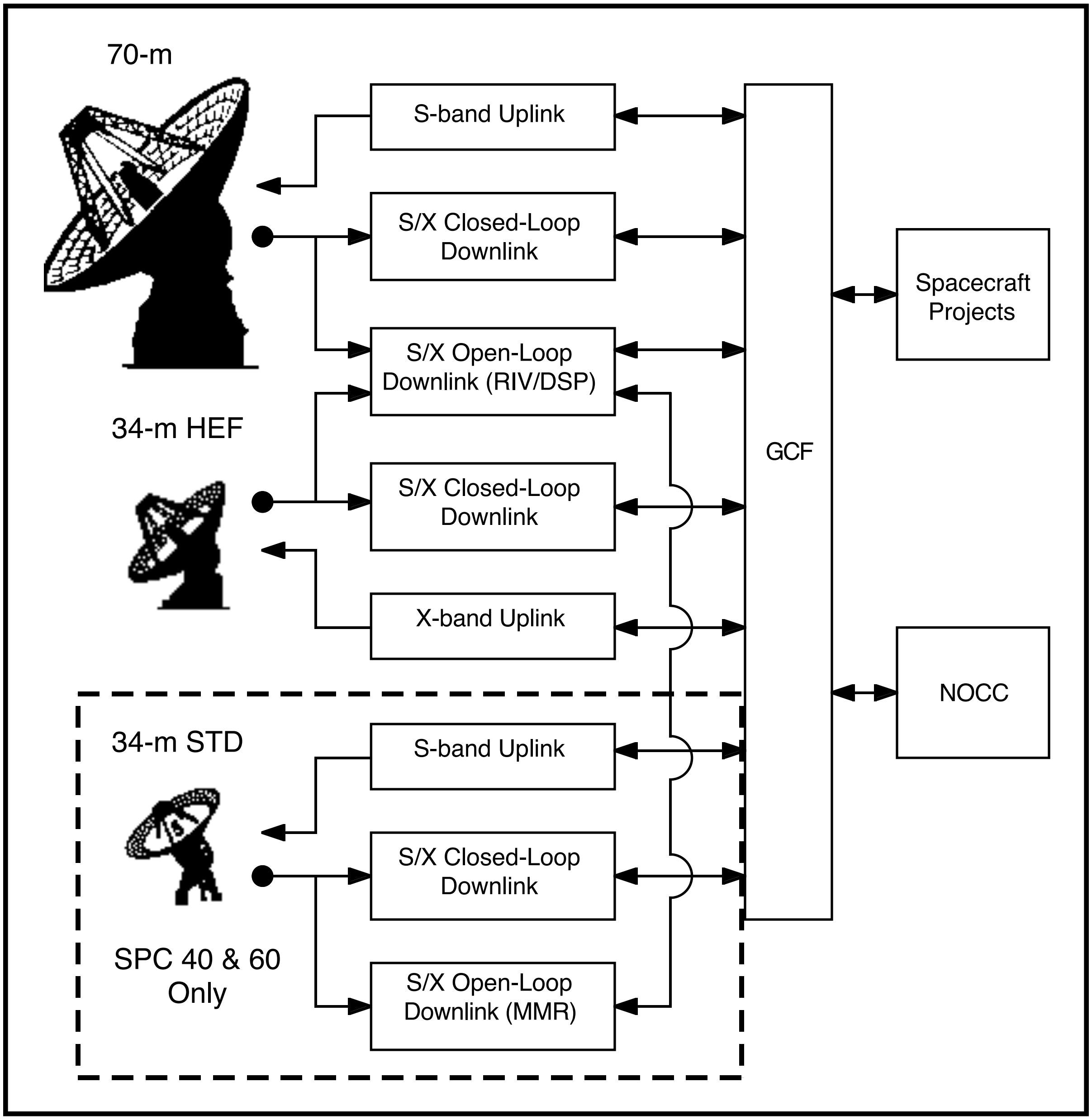

Figure 1. Radio Science System.

and X-band. These ranges are described in Table 1. A summary of the complexes and their capabilities is in Table 2.

Table 1. Receive Frequencies Applicable to Radio Science System

RSS Receive Frequencies			
S-band	2290 to 2302 MHz	X-band	8397 to 8440 MHz

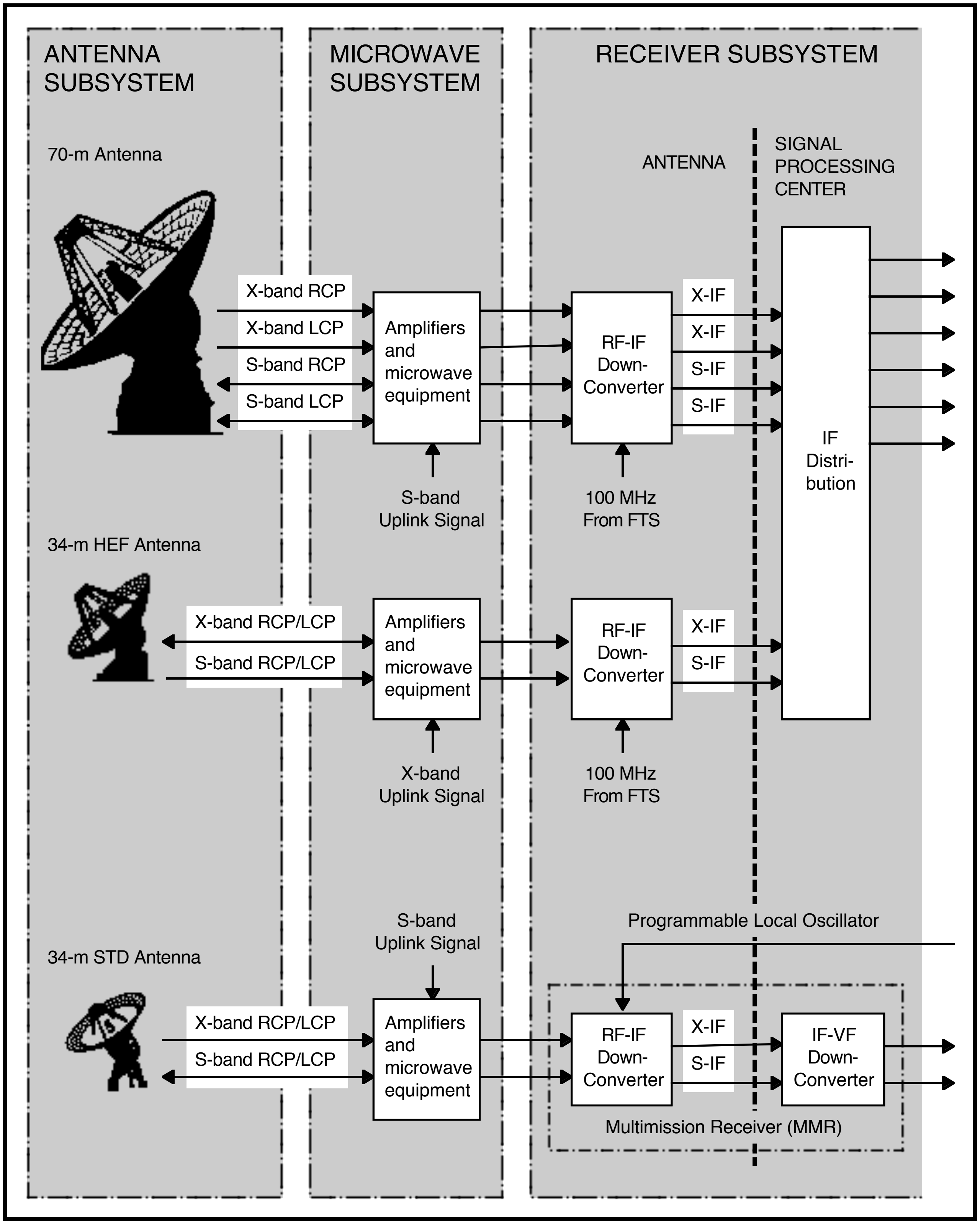

Figure 2a. Open-Loop Radio Science Receiving System (Sheet 1 of 3).

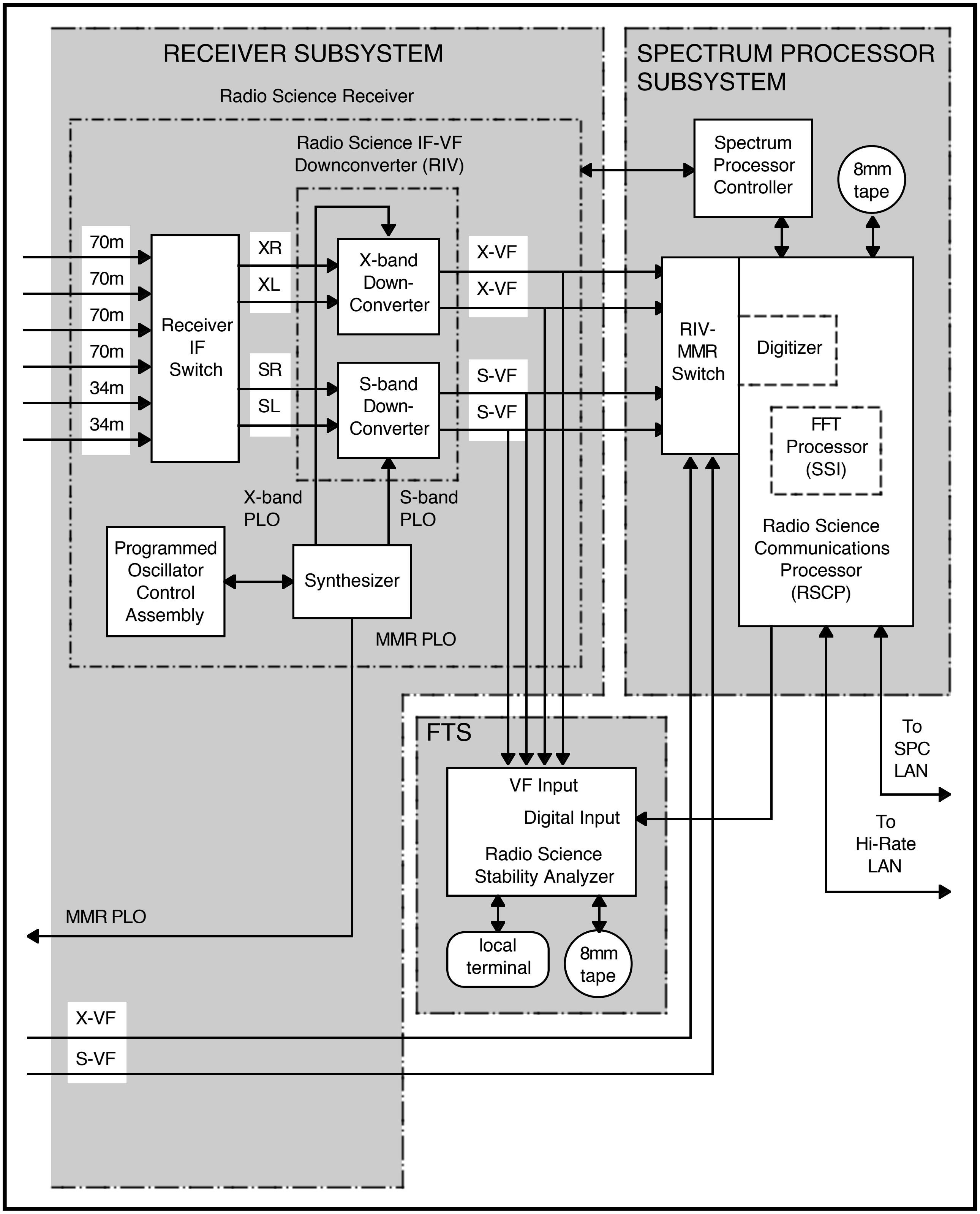

Figure 2b. Open-Loop Radio Science Receiving System (Sheet 2 of 3).

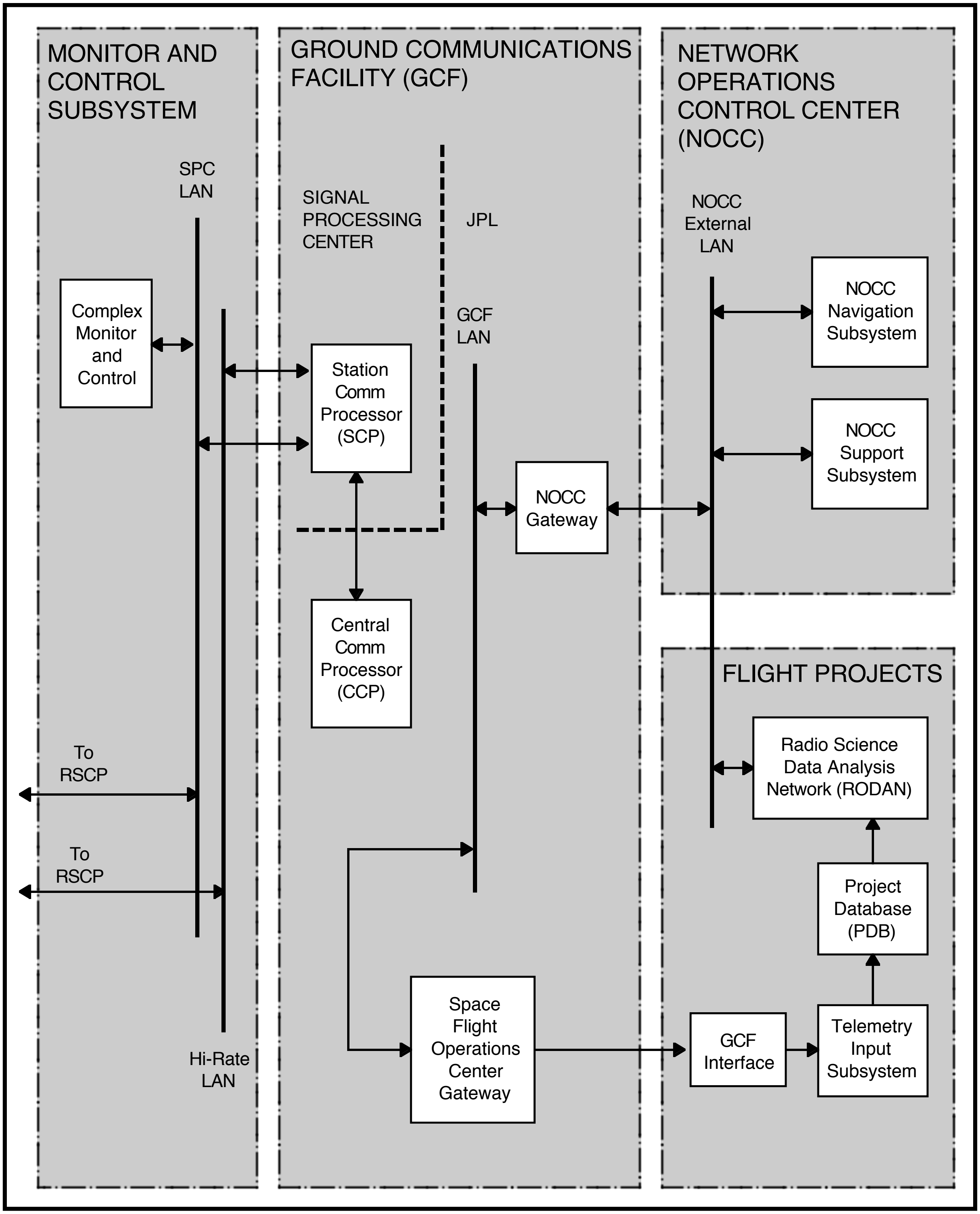

Figure 2c. Open-Loop Radio Science Receiving System (Sheet 3 of 3).

Table 2. DSN Equipment and Capabilities

DSCC-10		
Antenna	34 m HEF	70 m
DSS number	15	14
Uplink	X	S
Downlink	S or X	S & X
Fiber Optic FTS	Y	Y
RS Channels	2	4
RIV	1 (shared)	
DSP	1 (shared)	

DSCC-60			
Antenna	34-m STD	34 m HEF	70 m
DSS number	42	45	43
Uplink	S	X	S
Downlink	S & X	S or X	S & X
Fiber Optic FTS	N	Y	Y
RS Channels	2	2	4
RIV	0	2 (shared)	
MMR	1	0	0
DSP	2(shared)		

DSCC-60			
Antenna	34 m STD	34 m HEF	70 m
DSS number	61	65	63
Uplink	S	X	S
Downlink	S & X	S or X	S & X
Fiber Optic FTS	N	Y	Y
RS Channels	2	2	4
RIV	0	1 (shared)	
MMR	1	0	0
DSP	1 (shared)		

2.3 System Description

The Radio Science open-loop receiving system must record all the information which is contained in a specified bandwidth. To accomplish this, the bandpass of interest, centered around some radio frequency, is shifted to video band (near baseband) for digital sampling. The Radio Science open-loop system can process up to four RF channels. The channels are designated XRCP, XLCP, SRCP, and SLCP, corresponding to the right and left circularly polarized (RCP and LCP) signals available from the X- and S-band feedhorns.

2.3.1 Downconversion

There are two different mechanisms for signal downconversion, depending on the antenna chosen to support a particular experiment.

2.3.1.1 Downconversion at the 70 m and 34 m HEF Antennas (RIV Receiver)

The downconversion is carried out in steps, as shown in Figure 3. The first RF-IF downconversion, using a fixed local oscillator, occurs in the antenna.. The IF (approximately 300 MHz) signals are transmitted from the antenna to the Signal Processing Center (SPC), where the RIV receiver is located.

The RIV performs several stages of downconversion, the first of which is done via a programmable local oscillator. The synthesizer (DANA type) is driven by a programmable oscillator controller (the POCA), which uses predicts to determine a best carrier frequency. The synthesizer output is scaled to the incoming S and X IF channels (which are slightly different), and mixes both S-derived and X-derived signals down to 50 MHz plus a characteristic offset determined by frequency band and bandwidth selected. Along with mixing, the RIV dictates a bandwidth for recording through one of six crystal filters, selected through the RIV controller by operator command. A listing of four filters currently installed comprises Table 3; a listing of all filters available for ready installation is found in Table 4. The RIV also contains an attenuator, which is set by station operators based on the average predicted signal strength for a tracking pass. The attenuator prevents a signal from either saturating or under-driving the analog to digital converters (A/Ds) which will do the bandpass digitization.

After the signal has been digitized within the VF bandwidth, it is possible to reconstruct the original RF frequency received at the antenna though use of the formulas shown in Table 7. The RIV formulas reverse the specific downconversion (multiplication and addition) steps in the RIV receiver.

2.3.1.2 Downconversion at the 34m Standard Antenna (MMR Receiver)

The MMR receivers were the predecessors to the RIV receivers. In this older design, the first local oscillator has a programmable frequency output, and not the second local oscillator as in the RIV. Consequently, it is during the RF to IF downconversion that the signal is centered within a passband. For the MMR system, both the RF-IF and IF-VF converters are referred to as the "MMR".

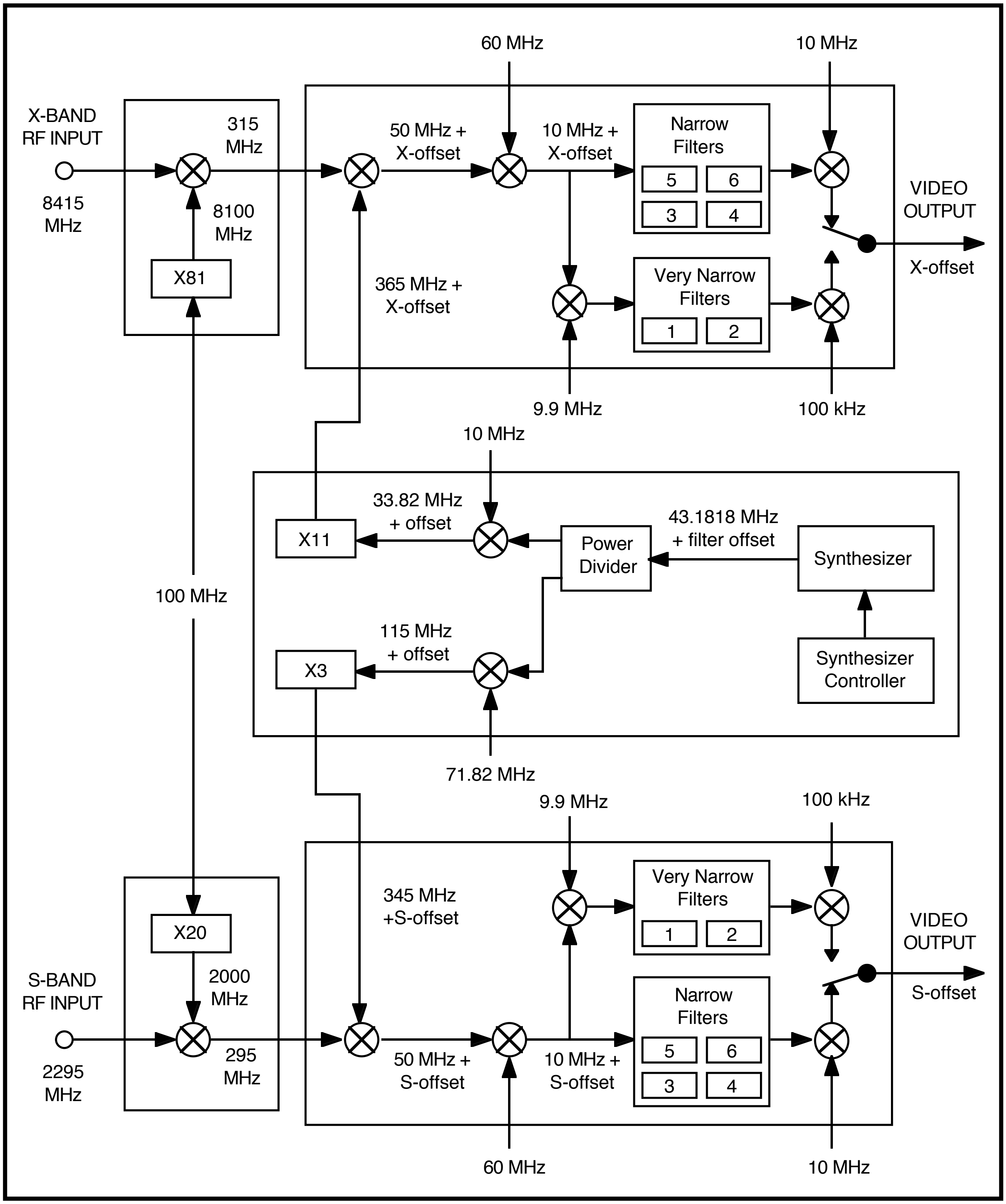

Figure 3. Downlink Frequency Conversion in the Open-Loop Radio Science Receiver, 70-m and 34-m HEF Antennas (RIV Receiver).

Table 3. RIV Filter Selections (as installed)

Filter Selection		X-band	S-band	Typical Usage
1	bandwidth (Hz)	82	82	Gravity Wave
	offset (Hz)	-550	-150	
	sampling rate (per sec)	200	200	
2	bandwidth (Hz)	415	-415	Solar Conjunctions
	offset (Hz)	-2,750	-750	
	sampling rate (per sec)	1k	1k	
3	bandwidth (Hz)	2,000	2,000	Mars Observer Occultations
	offset (Hz)	-13,750	-3,750	
	sampling rate (per sec)	5k	5k	
4	bandwidth (Hz)	6,250	1,700	Pioneer Venus Occultations
	offset (Hz)	+3,750	+1,023	
	sampling rate (per sec)	15k	5k	
5	bandwidth (Hz)	45,000	45,000	Sideband Analysis
	offset (Hz)	-275,000	-75,000	
	sampling rate (per sec)	50k	50k	
6	bandwidth (Hz)	20,000	20,000	Bistatic Radar
	offset (Hz)	-137,500	-37,500	
	sampling rate (per sec)	50k	50k	

Table 4. Available RIV Filters (installed and spare)

Filter Designation	Band	Bandwidth (Hz)	Offset (Hz)
1	X	82	-550
2	S	82	-150
3	X	415	-2,750
4	S	415	-750
5	X	2,000	-13,750
6	S	2,000	-3750
9	X	7,000	-55,770
10	S	7,000	-15,210
11	X	3,500	-27,500
12	S	3,500	-7,500
15	X	20,000	-137,500
16	S	20,000	-37,500
17	X	45,000	-275,000
18	S	45,000	-75,000
19	X	6,250	+3,750
20	S	1,700	+1,023
21	S	8,540	-15,000
22	S	4,500	-7,500

Table 5. MMR Filter Selections

Filter Selection		X-band (Hz)	S-band (Hz)
1	bandwidth	100	100
	offset	-550	-150
2	bandwidth	500	500
	offset	-2,750	-750
3	bandwidth	1,000	1,000
	offset	-5,500	-1,500
4	bandwidth	3,000	818
	offset	+1,500	+409
5	bandwidth	7,500	2,045
	offset	+3,750	+1,023
6	bandwidth	15,000	4,091
	offset	+7,500	+2,045
7	bandwidth	30,000	8,182
	offset	+15,000	+4,091

Table 6. Available Sampling Rates for Differently Sized Samples

8-bit Sample Rates (samples per second)			
200	1,250	5,000	20,000
250	2,000	6,250	25,000
400	2,500	10,000	31,250
500	3,125	12,500	50,000
1,000	4,000	15,625	
12-bit Sample Rates (samples per second)			
200	10,000		
1,000			
1,250			
2,000			
5,000			
16-bit Sample Rates (samples per second)			
1,250			

The RF-IF MMR, located in the antenna, receives the same programmable synthesizer frequency information as the RIV, although it is scaled to S and X RF rather than IF. The two channels of the RF-IF MMR are then sent to the IF-VF MMR, located in the Station Processing Center. As with the RIV, the IF-VF MMR has several stages of fixed-frequency downconverters and attenuators, and a set of crystal filters for anti-aliasing. Table 5 lists the MMR filters installed at SPC 40 (Australia) and SPC 60 (Spain). Filters are selected through the MMR controller by operator command.

After the signal has been digitized within the VF bandwidth, it is possible to reconstruct the original RF frequency received at the antenna though use of the formulas shown in Table 7. The two sets of MMR formulas reverse the specific downconversion (multiplication and addition) steps in the MMR receivers for Australia and Spain, respectively.

2.3.2 Sampling and Recording

The outputs of the MMR or RIV are within kilohertz of DC (0 hertz). This offset from DC is that which was included in the programmable local oscillator tuning for a particular filter configuration. The offset/filter relationships are listed in Table 2a, 2b, and 2c. This offset, along with the filter bandwidth, is important in the selection of the sampling frequency to be used when the VF signal is sent to the Deep Space Communications Complex Spectrum Processor data handler for digitization. The digitizer has four input channels, which may be assigned to any combination of four RIV channels (including redundant assignments) from any one antenna. Inside the digitizer, a selected pair of inputs may be sampled at a rate independent of that chosen for the other pair. The Deep Space Communications Complex Spectrum Processor can digitize the data as 8-, 12-, or 16-bit samples. Sampling frequencies for the different sample sizes are available from a discrete set, listed in Table 6. Sampling frequencies commonly associated with certain filters are indicated in Table 3.

Once sampled and digitized, the bandpass of interest is represented as a time-series of voltages. Frequency domain reconstruction of these samples will produce a noise bandwidth of one-half of the sampling frequency, with a representation of the carrier signal located at some position relative to the center of this bandwidth. The absolute value of this center frequency is determined by the synthesizer frequency which was being used at the time of the observation. Reconstruction of the true received RF frequency (the "sky frequency") requires undoing, mathematically, the various stages of downconversion in the radio-science receiver string. Formulas for frequency reconstruction are given in Table 7.

2.4 Interfaces

The Deep Space Communications Complex Spectrum Processor is part of a larger assembly called the Radio Science Communication Processor (RSCP). The RSCP serves as both data formatter and data distributor, for both outside users and various storage media.

Table 7. Received RF Frequency-Reconstruction Formulas

RIV Receivers (70 m and 34 m HEF)

$$F_{S\text{-band Sky}} = 3 \times (F_{Syn} + (790\times10^6)/11) + 1950\times10^6 - [Offset_S + (F_{Recorded} - 1/4\ F_{SampRate})]$$

$$F_{X\text{-band Sky}} = 11 \times (F_{Syn} - 10\times10^6) + 8050\times10^6 - [Offset_X + (F_{Recorded} - 1/4\ F_{SampRate})]$$

MMR Receivers (34 m STD)

DSS 42 (Australia)

$$F_{S\text{-band Sky}} = 3 \times (3/2\ F_{Syn} + 600\times10^6) + 300\times10^6 - [Offset_S + (F_{Recorded} - 1/4\ F_{SampRate})]$$

$$F_{X\text{-band Sky}} = 11 \times ((3/2 \times F_{Syn} + 600\times10^6) + (100\times10^6 \times 8/11)) + 300\times10^6 - [Offset_X + (F_{Recorded} - 1/4\ F_{SampRate})]$$

DSS 61 (Spain)

$$F_{S\text{-band Sky}} = 48 \times F_{Syn} + 300\times10^6 - [Offset_S + (F_{Recorded} - 1/4\ F_{SampRate})]$$

$$F_{X\text{-band Sky}} = 11 \times [(16 \times F_{Syn}) + (100\times10^6 \times 8/11)] + 300\times10^6 - [Offset_X + (F_{Recorded} - 1/4\ F_{SampRate})]$$

Legend:

$F_{S\text{-band Sky}}$	S-Band frequency received at antenna (RF signal)
$F_{X\text{-band Sky}}$	X-Band frequency received at antenna (RF signal)
F_{Syn}	Synthesizer frequency reported for a given second
$Offset_S$	S-band filter offset
$Offset_X$	X-band filter offset
$F_{SampRate}$	Digital sampling rate
$F_{Recorded}$	Carrier frequency as recorded in the digitized spectrum

2.4.1 Inputs

The Radio Science open-loop receiving system requires predicted values for spacecraft downlink frequency for the tuning of the synthesizer over the course of a tracking pass. Predict files are generated at JPL and transmitted to the station electronically.

2.4.2 Outputs

The RSCP normally provides data in two formats: real-time data blocks (per 820-13; RSC-11-11B) and 8mm (Exabyte) tape compilations (per 820-13; RSC-11-13). Table 8 provides a complete list of radio science data interfaces. Status information available from the Deep Space Communications Complex Spectrum Processor includes configuration data such as filter selection and channel assignment, monitor data such as analog voltage levels and synthesizer frequencies, and real-time fast Fourier transform (FFT) spectral images of the incoming signal. The FFT display is called the Spectrum Signal Indicator (SSI). Since the open-loop receivers have by definition no automatic mechanism for locating a signal, the SSI display is the only way to tell if a signal is indeed in the bandpass being recorded.

2.4.2.1 Advanced Multimission Operations System (AMMOS) Users

The Deep Space Communications Complex Spectrum Processor at the station, through the RSCP, routes formatted data blocks (820-13; RSC-11-12, RSC-11-11B, etc.) to the Station Communications Processor (SCP) to be transmitted to the Ground Communications Facility at JPL. The Ground Communications Facility will then route the data in real-time to AMMOS workstations, as well as archiving it in the on-line Project Database for later retrieval. In addition, 8 mm (Exabyte) Original Data Record (ODR) tapes (820-13; RSC-11-13) are created at the station; these are available at user request.

Monitor data from other systems (820-13; MON-5-15, TRK-2-15, etc.) also can be accessed through AMMOS workstations from both real-time broadcast and the Project Database.

Closed-loop Doppler information, packaged as Archival Tracking Data Files (ATDFs) or Orbital Tracking Data Files (OTDFs), are available as electronic files from the Project Database, or as 9-track tapes.

2.4.2.2 Other Users

All monitor data is sent in real-time, in formatted blocks, from the station to JPL. The GCF routes the data to JPL. Monitor data of interest (820-13; RSC-11-12, MON-5-9, etc.) is sent through serial interface to the Radio Science Data Analysis Network (RODAN), which is the radio science-specific monitoring and analysis system.

Open-loop carrier samples (820-13; RSC-11-13) are recorded on 8 mm ODR tapes at the DSCC sites and shipped to JPL. Data can also be played back at the end of the pass; in that case, an Intermediate Data Record (IDR) tape will be available from the GCF. Closed-loop Doppler and ranging information is packaged as ATDFs on 9-track tapes.

Table 8. Software Interfaces for Radio Science Data Types

Data Type	Interface
Open-Loop Samples	
• Real-time	820-13; RSC-11-11B
• IDR (ODR playback)	820-13; RSC-11-4A
• ODR	820-13; RSC-11-13
DSP/RS Receiver Monitor/Spectral Monitor (SSI)	820-13; RSC-11-12
Meteorological Data	820-13, TRK-2-24
Delay in Earth Ionosphere	820-13; TRK-2-23
Tracking System Monitor (Antenna Pointing Angles/Subreflector Position/Noise Temperature, etc.)	820-13; MON-5-15 (AMMOS) 820-13; MON-5-9 (other)
Closed-Loop (Doppler and Ranging) Configuration Monitor and Data	820-13; TRK-2-15

2.4.3 Radio Science Stability Analyzer

The Radio Science Stability Analyzer (RSA) is part of the Frequency and Timing Subsystem.(FTS) The purpose of this assembly is to provide real-time analysis of the performance of the Radio Science System. The Stability Analyzer can accept either VF input, directly from the RIV receiver, or digital samples from the Deep Space Communications Complex Spectrum Processor. The Radio Science Stability Analyzer has the capability to process four channels at a time, to a maximum sampling rate of 100 kHz. The performance characteristics generated by the Radio Science Stability Analyzer include power spectra and plots of frequency residuals and Allan variance.

The Radio Science Stability Analyzer cannot perform analysis on data from actual tracking passes, as it does not have the capability of removing spacecraft Doppler signatures. Therefore, the Radio Science Stability Analyzer can be used only with a test signal as signal source.

2.5 Performance

Performance metrics of the system are presented in this section.

2.5.1 Frequency Stability

Long-term frequency stability tests are conducted with the exciter/ transmitter subsystems and the Radio Science open-loop subsystem. An uplink signal generated by the exciter is translated at the antenna by a test translator to a downlink frequency. The downlink signal is then passed through the RF-IF downconverter present at the antenna, and into the Radio Science receiver chain. In doing this test, contributions from the Frequency and Timing Subsystem (FTS) and the Antenna Subsystem (ANT) cannot be measured. FTS noise is canceled out, due to the fact that the test path is essentially zero light time; the same FTS signals therefore reach each component of the uplink and downlink simultaneously. ANT noise is also excluded in this test, as the test signal is not actually transmitted and received with the antenna dish. Estimated FTS and ANT values, based on test data, can be factored in to measured stability. Though this test method measures only the two-way stability of the system, two-way tests have so far met the more stringent one-way requirements and are therefore the only tests performed. Frequency stability is quoted as the Allan variation over a specified integration time. Table 9 shows two-way measured system performance as well as estimated system performance (including FTS and ANT) for the 34 m HEF and 70 m subnets.

2.5.2 Phase Noise (Spectral Purity)

Phase stability testing characterizes stability over very short integration times; that is, spurious signals very close to the carrier. The phase noise region is defined to be frequencies within 100 kHz of the carrier. Both amplitude and phase variations appear as phase noise. Phase noise is quoted in dB relative to the carrier, in a 1 Hz band at a specified distance from the carrier: dBc-Hz at 10 Hz, for example. Table 10 contains sets of phase noise levels, at specified frequencies, for the 34 m HEF and 70 m subnets.

2.5.3 Amplitude Stability

Amplitude stability testing measures the amplitude variation produced by the open-loop receiving system on a constant amplitude test signal input. Amplitude stability is specified in terms of peak-to-peak amplitude variation over a specified period of time. Table 11 contains amplitude stability of the 70m and 34m HEF subnets.

Table 9. System Frequency Open-Loop Stability Radio Science with
34 m HEF and 70 m Subnets

34 m HEF Subnet						
Integration Time	FTS Contribution	ANT Contribution	DSCC-10 Static Test		DSCC-40 Dynamic Test	
	Measured	Estimated	Measured	Estimated	Measured	Estimated
1 s	2.0e-13	0.5e-13	5.5e-14	2.9e-13	1.2e-13	3.1e-13
10 s	4.0e-14	1.0e-14	9.7e-15	5.9e-14	2.7e-14	6.4e-14
100 s	8.0e-15	N/A	1.6e-15	N/A	1.9e-15	N/A
1000 s	1.53-15	1.0e-15	1.3e-15	2.9e-15	5.8e-16	2.6e-15
3600 s	N/A	N/A	2.5e-15	N/A	9.3e-16	N/A
5000 s	N/A	N/A	6.4e-16	N/A	1.3e-15	N/A
70 m Subnet						
Integration Time	FTS Contribution	ANT Contribution	DSCC-10 Static Test		DSCC-40 Dynamic Test	
	Measured	Estimated	Measured	Estimated	Measured	Estimated
1 s	2.0e-13	0.5e-13	4.3e-13	5.1e-13	3.7e-13	4.7e-13
10 s	4.0e-14	1.0e-14	7.0e-14	9.1e-14	1.0e-13	1.2e-13
100 s	8.0e-15	N/A	N/A	N/A	1.3e-14	N/A
1000 s	1.5e-15	1.0e-15	1.8e-15	3.1e-15	2.2e-15	3.4e-15
3600 s	N/A	N/A	N/A	N/A	2.1e-15	N/A
5000 s	N/A	N/A	N/A	N/A	2.8e-15	N/A

Notes

- N/A: not available
- "Dynamic" test involves ramped uplink;
- "static" test uses constant frequency
- FTS and ANT contributions are one-way
- Measured values are those specifically registered in test
- Estimated values are the root-sum-squared combination of two FTS, two ANT, and measured values, producing estimated total system performance in two-way mode
- See text (Section 5.1) for further description of test procedures

Table 10. Open-Loop Radio Science System Phase Noise with 34 m HEF and 70 m Subnets

34 m HEF Subnet	
DSCC-60	
Offset from Carrier	**Noise (dBc)**
1 Hz	-54.07
10 Hz	-60.17
100 Hz	-74.00
70 m Subnet	
DSCC-40	
Offset from Carrier	**Noise (dBc)**
1 Hz	-54.07
10 Hz	-60.17
100 Hz	-74.00

Table 11. Open-Loop Radio Science System Amplitude Variation with 34 m HEF and 70 m Subnets

34 m HEF Subnet		
Averaging Time	**X-Band Variation**	**S-Band Variation**
20 minutes	TBD	TBD
4 hours	TBD	TBD
70 m Subnet		
Averaging Time	**X-Band Variation**	**S-Band Variation**
20 minutes	TBD	0.06 dB
4 hours	TBD	0.30 dB